THE NASA LANGLEY RESEARCH CENTER'S GENERAL AVIATION BASELINE RESEARCH SYSTEM

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Abstract:

This paper describes the architecture, capabilities, and design considerations of a common baseline research system, which was developed at the NASA Langley Research Center for use in its three general aviation research aircraft. NASA Langley has acquired a Cessna 206X Stationair, Lancair Columbia 300X, and a Cirrus Design SR22X aircraft to support a variety of NASA flight-research programs, in particular the Small Aircraft Transportation System (SATS) Project, and the Aviation Safety Program. The SATS Program is a partnership involving NASA, the FAA, states, industry, and universities to develop key enabling transportation technologies.

A set of general aviation research requirements was developed, and a baseline research system architecture was derived from those requirements. The baseline design requirements include: modular architecture; standard interchangeable components; re-configurable equipment mounting; and, an extensive sensor suite [1]. A combination of commercial off-the-shelf (COTS) and custom-designed systems were selected, purchased or fabricated, and installed. These systems include: separate research power; multi-function flat-panel displays; state sensors; airborne internet; serial data bus; video recording; data acquisition; data-link; Global Positioning System (GPS)/Differential GPS (DGPS); telemetry; and instrumentation. Several open architecture standards were used in the selected research equipment. These open standards include: Ethernet; Controller Area Network (CAN); Intel x86-based computers; and the Common Airborne Instrumentation System (CAIS).

The Cirrus Design SR22 and Lancair Columbia 300 aircraft are small, single-engine, four-place, composite-construction aircraft with limited payload and electrical power. These attributes presented significant additional design challenges beyond those associated with the implementation in the Cessna 206X, a six-place metal aircraft. The Cirrus Design SR22 was the first of the three aircraft to be outfitted with the "General Aviation Baseline Research System", and is currently conducting SATS research experiments. The resulting system is meeting NASA Langley's flight-research needs, and advancing the use of the latest technology in general aviation.

Introduction

Based on inputs from researchers, implementers, and managers, a Baseline General Aviation Aircraft Research System Requirements Document was written which sets forth requirements for a generic research system to be installed in each of the three general aviation (GA) aircraft at NASA Langley. The document specifies the following three objectives for the design of the research system: 1) minimize the cost and time required to reconfigure an aircraft for each experiment by incorporating a modular architecture; 2) minimize costs by using standard components that can be interchanged between aircraft; and, 3) minimize the data reduction costs by using a common data recording system for all three aircraft [1].

Due to time, budget, and manpower considerations, it was decided that the team would concentrate its efforts on the Cirrus SR22X aircraft for the initial research system implementation. It was also decided that the Cirrus tasks would be broken into two phases. Phase I implementation included all those requirements necessary for the first SATS High-Volume Operations research experiment along with most of those found in the baseline requirements document. Phase I systems include: research power; research equipment pallet; data acquisition and recording; data link; GPS and DGPS; aircraft state, engine, surface positions, and air-data sensors; one flat-panel multi-function display (MFD); operator workstation; video recording; and general-purpose research computers. The baseline research system hardware architecture block diagram is shown in Figure 1.

The Cirrus SR22X aircraft made the first instrument check flight in the Phase I configuration on May 14, 2003. Phase II implementation will commence at the conclusion of the current SATS flight research experiment. Other SATS experiments and demonstrations will make use of the Phase II configuration.

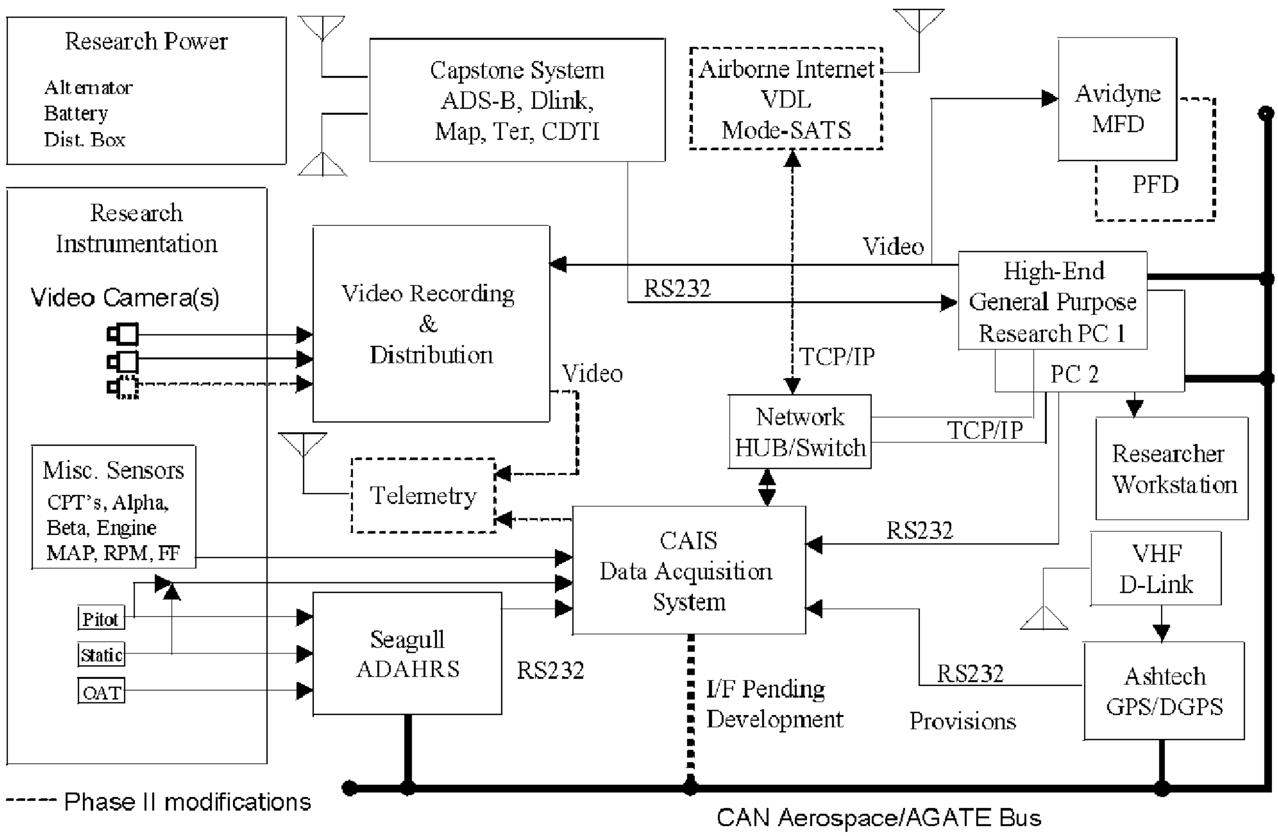

Figure 1. Baseline Research System Block Diagram

The Cirrus Design SR22X Aircraft

The Cirrus SR22X is a composite construction, single-engine, four-place production GA aircraft manufactured by Cirrus Design of Duluth, Minnesota. The SR22 is one of several new-generation GA aircraft making use of the latest in materials, aerodynamics, avionics, and manufacturing technology. The SR22 aircraft received Federal Aviation Administration (FAA) certification in 2000, with over 600 aircraft having been delivered since that time. One of the innovative design features of the SR22 aircraft is the Cirrus Airframe Parachute System (CAPS). The CAPS is an emergency parachute system that can be deployed by the pilot or a passenger to safely slow and lower the entire airplane to ground if controlled flight is no longer possible.

The aircraft design makes use of single-handed side control yokes instead of traditional two-handed control yokes. The NASA Langley Cirrus SR22X aircraft, N501NA, is shown in Figure 2. The aircraft has a research configured empty weight of 2512 lbs, a gross weight of 3400 lbs, a load capacity of 988 lbs, and a fuel capacity of 81 gal (486 lbs). The engine is a 310-hpTeledyne Continental model IO-

550-N with 6 cylinders, fuel injection, and is normally aspirated. The SR22 aircraft has a wingspan of 38.3-ft, length of 26.0-ft, and a height of 8.8-ft. Performance specifications include a cruise speed of 180 knots, climb rate of 1400 ft/min, takeoff roll of 1100-ft, and a ceiling of 17,500-ft.

As delivered to NASA, the aircraft avionics suite includes: dual Garmin GNS 430 GPS/communication/navigation units; S-TEC autopilot; Garmin GTX 327 Mode-C Transponder; Garmin GMA 340 Audio Panel; Sandel Electronic Horizontal Situation Indicator (EHSI); digital altitude encoder; and, an ARNAV 10.4-in. diagonal flat-panel MFD. The GNS 430 units are certified for Instrument Flight Rule (IFR) approaches, and include the following components: Very-High Frequency (VHF) communications transceivers, and receivers for GPS, VHF Omnirange (VOR), Instrument Landing System (ILS), Glide Slope, and Marker Beacon. The production avionics systems also include an emergency locator transmitter (ELT). Standard instrument gauges include: true airspeed indicator; electric attitude indicator; altimeter; turn coordinator; vertical speed indicator; GPS/ILS indicator; magnetic compass; fuel quantity gauges, manifold pressure/fuel flow gauge; oil temperature/oil pressure gauge; Exhaust Gas Temperature/Cylinder Head Temperature (EGT/CHT) gauge; and, voltage/amperage gauge.

Figure 2. Cirrus Design SR22

Description of the GA Baseline Research System

Power System

In order to preserve the integrity of the basic aircraft power system, it was decided to implement a completely separate power system for the research systems. This decision required installing a separate research alternator, battery, power control, and distribution system. A survey of available components revealed that a high-output alternator was developed by Northcoast Technologies under a NASA Glenn Research Center Small Business Innovative Research (SBIR) grant. The high-output alternator was developed as part of a thermoelectric ice protection system designed for GA aircraft. Northcoast Technologies is the holder of the Parts Manufacturer Approval (PMA) and all Supplemental Type Certificates (STC's) to be issued for the power system and de-ice system.

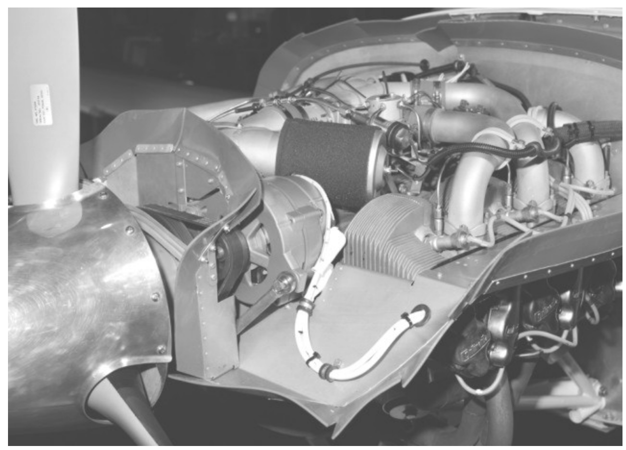

Figure 3. Experimental System Alternator

Northcoast Technologies was contracted by NASA Langley to make the necessary aircraft air duct and baffling mechanical modifications and to install the alternator brackets and the alternator in both the SR22X and the Lancair Columbia 300X aircraft. NASA personnel installed the alternator controller, battery, and wiring. The research alternator installation is shown in Figure 3. NASA personnel also designed, fabricated and installed the power control, wiring and power distribution system. An Experimental Systems Control Panel (see Figure 4) was designed, fabricated, and installed in the aircraft center console. The panel provides the means for the entire crew to enable, disable, and monitor the research power system from one central location. The panel contains lights, switches, circuit breakers, and a meter for monitoring voltage, current, under-voltage, and alternator failure. The panel also contains switches and indicators for the control and monitoring of the data and video recording systems. If there is any question about the integrity of the research systems, the entire system may be shut down with the flip of one switch.

The research power system was designed to supply a maximum of 50 A at 28 V, or 1.4 KW. The 16-lbs alternator is capable of producing up to 6.5 KW of power, but the system was purposely limited by wire size and circuit breakers to 50 A. The entire Phase I research system currently draws a total of 15.0 A of 28 VDC research power, which the alternator can supply at engine idle speed. The alternator is belt driven from the engine; testing has shown that engine power is reduced less than 1 percent by the alternator. Northcoast personnel prepared and submitted the one-time STC form 337 to the FAA for field approval of the installation.

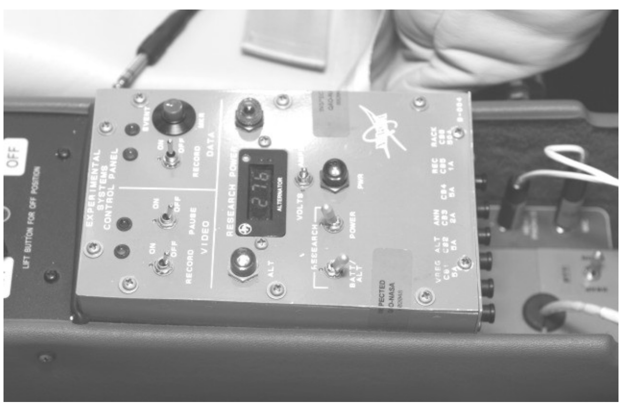

Figure 4. Experimental System Control Panel

Research Equipment Pallet

The requirements in Reference 1 called for providing research equipment pallets for mounting baseline and customer-provided components in the three NASA GA airplanes. The team designed a common pallet, which could fit into the existing aircraft cargo space behind the passenger cabins in both the Cirrus SR22X and Lancair Columbia 300X aircraft. The pallet and its associated mounting hardware are required to withstand longitudinal crash loads of 18 times the force of gravity (18 G's), per the Federal Aviation Regulations [4]. This requirement is intended to minimize injuries to passengers caused by loose equipment during a crash. Finally, the total weight of the pallet and all research equipment mounted on the pallet must not exceed the aircraft design weight limit of the cargo space, which is 130-lbs.

The resulting design is a two-shelf, trapezoid-shaped pallet constructed of 0.625-in. thick aircraft-grade aluminum honeycomb. The honeycomb material selected is constructed of a 1/4-in. cell 5052-3.4 aluminum honeycomb core clad with 0.020-in. thick 2024T3 aluminum sheet. The shelf supports are constructed of 0.050-in. thick 2024-T351 aluminum sheet that has been folded to form 90-deg corner supports. The supports are flanged and holes are cut and flanged to increase stiffness. Vertical spacing between the two shelves is 10 in. to allow sufficient clearance for the largest pieces of equipment. The top shelf is smaller than the bottom in order to fit the cargo area and to allow room for the inclined rear seats. Special lightweight composite fasteners are used to secure the pallet to the cargo floor, the shelves to the corner supports, and the equipment to the shelves. The fasteners are designed to allow secure fastening without crushing the aluminum honeycomb. The total empty weight of the equipment pallet is 14 lbs. The pallet installed in the SR22 with research equipment is shown in Figure 9.

Analysis of the pallet design demonstrated that it would withstand the required 18-G load with a maximum of 120 lbs of research equipment. A constraint of the design limits the total top-shelf equipment weight to a maximum of 40 lbs. The bottom shelf can support the full 120 lbs. The common pallet design allows interchangeability between the Cirrus SR22X and Lancair Columbia 300X aircraft.

Air Data, Attitude and Heading Reference System

The Sequoia Instruments' GIA-2000 Air Data, Attitude and Heading Reference System (ADAHRS) is used to provide air data, heading, three-axis attitudes, three-axis accelerations, and

GPS navigation information. Several GIA-2000 systems were previously acquired for flight research use by the NASA Advanced General Aviation Transport Experiments (AGATE) program. The GIA-2000 system is comprised of a 5-lb main unit and a three-axis magnetometer. The main unit is 5.66-in. wide, 4.84-in. high, and 8-in. long. The main unit has inputs from pitot and static pressure sensors, an Outside Air Temperature (OAT) probe, a GPS antenna, and the magnetometer. The unit operates on 28-V DC power. The unit outputs data blocks at three rates via a RS-232 serial data bus at 57,000 baud.

The ADAHRS main unit is located on the bottom shelf of the research equipment pallet in the Cirrus SR22X aircraft. The magnetometer is located inside the right wing near the wing tip.

CANAerospace/AGATE Data Bus

The AGATE data bus was added to the research system to provide interoperability of avionics from different manufacturers using standard off-the-shelf components. The AGATE data bus is based on the CAN bus that has been used in the automotive industry for a number of years. The CAN standard is a sub-set of the 1-MBit/sec, two-wire multi-transmitter CANAerospace protocol, an open, royalty-free protocol. It is used to define both the physical and data-link layers. The CAN protocol is generally implemented in silicon to ensure speed, robustness and interoperability at the hardware level. Because of its reliability, simplicity, efficiency, and integrity, the production of bus interface chips exceeds 100 million units today. The overlaying CANAerospace protocol was originally developed by Stock Flight Systems in Germany and was standardized by NASA as a next-generation GA data bus during the AGATE program in 2001 [2]. Its major advantages are outstanding reliability, simplicity, robust error detection, and a self-identifying message format that supports the interoperability of systems produced by different vendors.

The CAN/AGATE bus is used in the SR22X airplane as a backbone network for the GIA-2000 ADAHRS, the Ashtech Z-Xtreme GPS receiver, and the general-purpose research computers. The bus interface hardware and software development tools were purchased from Stock Flight Systems. The bus components include the NECSmini interface system, bus wiring, and bus terminators. The NECSmini accepts analog and digital inputs for conversion to CAN bus signals and connects to other bus components. The NECSmini contains a 28-V power supply, 68376 processor, 16-channel analog-to-digital (A/D) converter, and time processor. The NECSmini sub-systems are all contained in a sealed aluminum case that weighs one pound. The ADAHRS outputs attitude sensor data at a 50-Hz rate, air data at 5-Hz, and GPS data at 1-Hz via a RS-232 serial stream at 57,000 baud. The RS-232 data are input to the NECSmini interface box that translates the signals to the CAN bus. The Z-Xtreme GPS selected message data are also input to the NECSmini in the RS-232 format at a 10-Hz rate. This configuration of components loads the data bus to 17 percent of capacity, leaving considerable growth capacity. The AGATE/CAN bus can also be expanded by adding multiple buses, as needed, to reach the desired capacity.

Operator Workstation

An operator workstation is required to control, configure and operate the two general-purpose computers and to monitor the data parameters. A workstation display was created from off-the-shelf parts, including a 10.4-in. liquid crystal display (LCD), display controller card, and display brightness and menu controls. The LCD pixel resolution is a technology-leading 1024 x 768 with a brightness rating of 1600 nits. The display enclosure was designed specifically for the display components by the engineering team and fabricated using computer-aided manufacturing (rapid prototyping). The workstation display is mounted to the back of the right front seat for use by the operator seated in the right rear seat. A joystick-mouse controller and three mouse buttons are installed in the right rear armrest. A keyboard connection is also installed in the armrest for use with a standard keyboard or a special arm-worn keyboard. A keyboard-video-mouse (KVM) switch is used to switch between the general-purpose computers, and is switched via keyboard commands. The Operator Workstation is shown in Figure 5.

Figure 5. Operator Workstation

Avidyne Multi-Function Display

The Avidyne 10.4-in. diagonal MFD is the only research display located in the main instrument panel during the Phase I research configuration. The MFD is a modified version of the FAA-certified FlightMax EX5000 that is in production for the Cirrus, Diamond, and Lancair aircraft. The certified version has many features, including a GPS-driven moving map and the capability to display flight plan, terrain, traffic, airspace, lightning, navigational aids, and other information. The display has a 800 x 600 LCD with two rotary knobs and ten bezel buttons for display and mode control. Two landscape-oriented units were purchased by NASA for the SR22X airplane, and two portrait units for the Lancair Columbia 300X.

The NASA MFD's were modified by Avidyne to output the knob and bezel-button settings over an RS-232 serial bus for input to the general-purpose computers. The units were also modified to output display video over a low-voltage differential serial (LVDS) data bus. The units also accept LVDS inputs from the research system to display research images on the MFD. The "Research" and "Native" modes are selectable by the pilot via a switch on the main instrument panel. In the "Native" mode, the MFD operates exactly like the FAA-certified system. In the "Research" mode, the MFD will only display computer-generated images from one of the general-purpose research computers.

Data Acquisition System(DAS)

The baseline data acquisition requirements called for a system with the capability to digitally record a minimum of 250 parameters at a rate of 50 Hz with a 12-bit resolution. The requirements also specify that the DAS must be able to record specific time-coded data, including: aircraft state parameters; air data; navigation information; control-surface positions; angular rates; linear accelerations; discrete events; and, engine parameters [1]. Following a review of many data systems, the team selected the CAIS. The CAIS is a generic standard developed by the Department of Defense to promote standardization, commonality, and interoperability among the flight-test community. The CAIS concept is based upon a standard modular compliment of hardware that can be used on a wide variety of programs. The team chose the CAIS components manufactured by the Teletronics Technology Corporation (TTC). TTC makes a set of hardware systems and modular components for the purpose of acquiring, conditioning and recording many types of analog and digital signals. The TTC CAIS equipment is of high quality and meets several rigid military standards. This equipment is also used to support flight-test operations at the NASA Dryden Flight Research Center in California and the Naval Air Warfare Center in Maryland.

The main component of the research DAS is the CAIS Data Acquisition and Encoding Unit (CDAU) Model CDAU-2016. The CDAU is a basic chassis unit with 16 slots for accepting modular cards for interfacing to a variety of analog/digital sensors and sources. Cards can be selected and installed to meet specific data recording requirements and changed to meet changing requirements. Additional chassis can be connected through CAIS standard bus architecture to expand the number of recorded data channels. The system is re-configurable and fully programmable with a nominal capacity of up to 8000 input channels. Data can be recorded to solid-state memory at a programmable maximum rate of 5 Mbits/sec with 12-bit resolution. The CDAU-2016 unit is 4.97 in. wide, 5.40 in. high, and 13.98 in. long. The CDAU weighs approximately 12 lbs, and consumes approximately 80 W of power at 28 V [3]. This research component is located on the bottom shelf of the research equipment pallet.

Sensor System

In order to satisfy the requirement to record control-surface positions, side control yoke positions, and engine parameters, an extensive set of sensors were installed in the SR22X airplane. Control-position transducers (CPT's) were installed to record the position of the flaps, ailerons, elevator, elevator trim motor, rudder, throttle, and the pilot's left side control yoke. Other types of sensors were installed to measure and record engine manifold pressure, propeller revolutions per minute (RPM), fuel flow, and OAT. The DAS CDAU provides the excitation voltages for the sensors, and directly records all of the sensor outputs.

A Systron Donner MotionPak II instrumentation-grade solid-state inertial sensing system was installed to measure three-axis linear accelerations and three-axis angular rates. The motion package is installed on the floor of the aircraft in the passenger cabin, near the aircraft center of gravity. A Crossbow VG700CA-200 avionics quality Fiber Optic Gyro was also installed to provide aircraft attitude information and serve as a redundant source of accelerations and angular rates. The Crossbow unit is an intelligent vertical gyro implementing proprietary algorithms and digital signal processing to compensate for deterministic errors. A research air data boom and transducers were installed to provide static and dynamic pressures, as well as the angles of attack and sideslip. The air data boom is described separately.

Air Data Boom

A completely separate research air data system was implemented in order to preserve the integrity of the basic aircraft air data sensors. The main element of the system is a small 11-oz air data boom made by SpaceAge Controls that contains total and static pressure ports as well as angle of attack (alpha) and angle of sideslip (beta) sensors. Since the SR22 airplane has removable wingtips, another wingtip was purchased for the installation of the boom and associated transducers. The new wingtip with air data boom, transducers, wiring, and plumbing was installed on the right wing in place of the original. The wingtip total pressure and static pressure transducers are connected directly to the DAS for recording. The alpha and beta vane sensors are excited and read directly by the DAS CDAU. The total and static port plumbing from the air data boom is also connected to the ADAHRS located on the research equipment pallet for use by the sensors contained within. The air data boom and wingtip are shown in Figure 6.

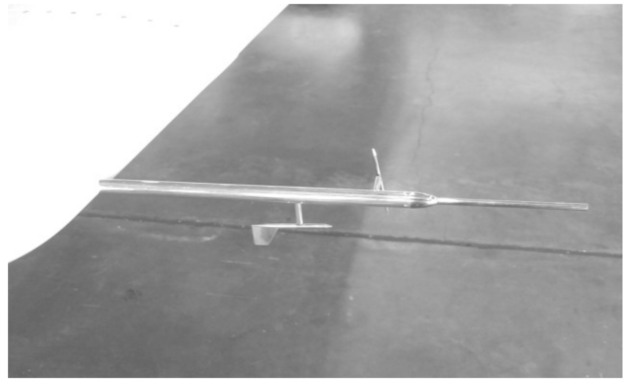

Figure 6. Air Data Boom

General-Purpose Computers

Two general-purpose research computers were fabricated from available commercial parts. Motherboards were selected and purchased in the standard 5.75-in. by 8-in. Embedded Board eXpandable (EBX) form factor. The boards are configured with 1-GHz Intel Pentium III processors, 500-MB memory, dual 10/100 base-T network connections, four RS-232 ports, one accelerated graphics port (AGP), National Television System Committee (NTSC) standard video, and expansion via Integrated Device Electronics (IDE), Peripheral Component Interconnect (PCI), and PC104 standard ports.

The motherboards, power supplies, and CANAerospace/AGATE data bus interface cards are mounted in 3-in. x 6-in. x 14-in. aluminum enclosures, that are installed on the bottom shelf of the research equipment pallet. The computer software is contained on flash memory cards rather than on rotating hard disks. The computers were tested with a variety of operating systems including Microsoft Windows 98, QNX, and Linux.

The Ethernet ports are used to provide a communications link between the two general-purpose computers and other research systems. A five-port Ethernet hub is used to connect the two computers with the CAIS and Airborne Internet (Phase II). A network hub connection to the equipment pallet front panel provides an external connection to both computers for software loading and other functions.

Four RS-232 ports in each computer are used to interface to several systems including standard ship's GPS receivers, the Capstone system, CAIS, Ashtech GPS receiver, VHF radio modem, and Avidyne MFD bezel button outputs. The RS-232 signals are wired in parallel with a 12-position rotary switch on the pallet front panel. This switch provides a means to monitor the RS-232 signals from an internal or external computer or terminal.

Video System

The video design requirements include time-synchronized video recording, two cabin-mounted cameras, one tail-mounted camera, and video telemetry [1]. The implementation team designed a Phase I research video system consisting of two cabin-mounted miniature video cameras, three miniature digital video recorders, two camera control units (CCU's), switches, video distribution amplifiers (VDA's), and a video time inserter. All of the video components were selected from COTS equipment made by a variety of manufacturers. Elmo made the 1/2-in. charge-coupled device (CCD) color cameras, CCU's, camera cables, and lenses. Three 2-lb Sony DSR-V10 MiniDV digital video cassette recorders were selected to record all audio and video images. A Sekai Model REI-2784 four-channel Ruggedized Video Time Inserter (VTI) was selected to insert GPS synchronized universal coordinated time (UTC) into each video channel. The Video Accessory Corporation made the selected miniature video switches and VDA's.

The mechanical engineering team designed and produced camera mounts that are adjustable in azimuth and elevation and can be locked in position. The team also designed a method to attach the camera mounts to solid blocks of composite material bonded directly to the cabin overhead fuselage surface. The cameras provide simultaneous recording of aircraft instruments and pilot-copilot actions, depending on camera look angle and field of view (as determined by the interchangeable lenses). The third video recorder provides a means to record the research images displayed on the MFD, which are generated by the general-purpose computers.

The video requirements for a tail-mounted camera and a means to send the video images via telemetry to a ground station were deferred until Phase II. However, the design of the tail-camera mount was completed. The combination of adjustable cameras, interchangeable lenses, video switches, and VDA's makes the video system flexible, adjustable and easily reconfigurable to meet research needs. The two cabin mounted video cameras are shown in Figure 7.

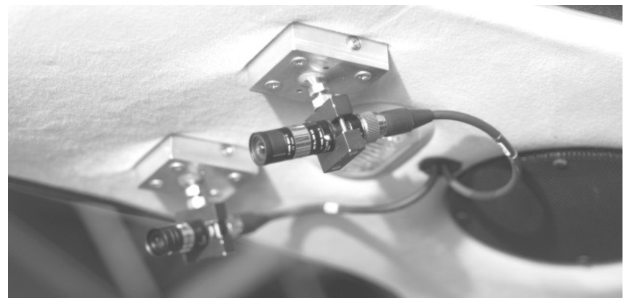

Figure 7. Cabin cameras

Audio System

Baseline audio requirements include the ability to record all VHF radio and intercom channels [1]. The three video recorders are used to satisfy this requirement, with each capable of recording two audio channels. The VTI supplies the time synchronization, an additional requirement. Wiring was added to the aircraft to bring the pilot, co-pilot, and passenger headset audio interphone channels to the video recorders on the research equipment pallet. Connections were also made from general-purpose computer audio outputs to the interphone system through existing audio jacks on the center console. This last modification was a research requirement specifically for the first SATS experiment. A separate audio input channel (which is not connected to the interphone) is also provided to record comments from the researchers during flight tests.

Capstone System

The Capstone system was developed by the FAA to test and evaluate several technological innovations in a large number of GA aircraft in Alaska. These innovations include automatic dependent surveillance broadcast (ADS-B), cockpit display of traffic information (CDTI) from traffic information services broadcast (TIS-B), flight information services broadcast (FIS-B), terrain avoidance information, and weather information.

These capabilities are currently experimental, but are expected to become available in certified avionics systems in the future. The Capstone suite was added to the research system to provide ADS-B, CDTI, data link, the display of weather information, and to be compatible with other SATS partners using the same system.

The system primarily consists of an MX20 MFD and a Universal Access Transceiver (UAT), that are both mounted on the research equipment pallet. The MX20 contains a GPS receiver, processor, 5-in. diagonal flat-panel color display, and several databases. The UAT is a 1-MB/sec transceiver that transmits and receives ADS-B messages and receives TIS-B, FIS-B, and weather data broadcast from ground-based systems. The UAT data-link output is connected to one of the general-purpose research computers via a RS-232 serial interface. This interface allows the computer to process the ADS-B, TIS-B, FIS-B, and weather data for display on the research MFD mounted in the main instrument panel.

GPS System

The research GPS system consists of a dual-frequency multi-mode phase-tracking receiver, separate GPS antenna, radio-frequency (RF) splitter, and a VHF radio modem to receive differential corrections. The Thales Navigation Ashtech Z-Xtreme was chosen for the main research GPS receiver due to its capability and compatibility with existing Ashtech Z-12 receivers. The Z-Xtreme is a dual-frequency (L1/L2) phase-tracking receiver capable of real-time carrier phase or code-phase differential GPS. The receiver can output real-time data at a rate of 10-Hz and record raw carrier-phase data to removable solid-state memory for post-processing applications. A narrow-band VHF radio modem is used to receive code-phase differential GPS corrections from compatible ground stations.

A Sensor Systems S67-1575-96 dual-frequency GPS antenna with integral 40-db preamplifier is used for the research GPS system. The antenna is mounted under the glare shield beside the basic ship's number two GPS antenna. A total of two single input/quadruple output GPS power splitters are used to distribute the antenna output to a maximum of eight GPS receivers. In addition to the Z-Xtreme, several embedded GPS receivers make use of six of the eight available signals. The ADAHRS uses one of these signals and supplies the 5-V DC to power the GPS antenna preamplifier. Embedded GPS receivers in the video time inserter, the CAIS CDAU, and the Capstone MX20 use an additional three signals. The Phase II Airborne Internet transceiver will make use of an additional GPS signal, leaving two available for future expansion.

Antenna System

Six additional antennas of various types were added to the aircraft for various research systems. The mechanical engineering team produced a universal antenna adapter design to allow mounting a variety of antennas of different sizes and shapes to the aircraft. Each adapter is fabricated with a flat antenna mounting surface on one side and a conformal surface that matches the aircraft skin at that location on the other. The adapters were fabricated from 1/2-in. aluminum stock with six mounting holes for attaching to the aircraft. Holes were drilled in the adapter for the specific antenna connector, and mounting holes and helicoils were installed for the antenna mounting screws. The team specified the antenna locations in an attempt to maximize space between antennas in order to minimize RF interference. The antenna adapter allows changing the antenna without modifying the original aircraft hull penetration and adapter mounting holes. The procedure for changing an antenna involves fabricating another adapter for that specific location with antenna connector and mounting holes for the new antenna. The new antenna and adapter then replace the old antenna and adapter. Five external antennas were installed, including top and bottom UAT blade antennas, two VHF antennas, and an S-band telemetry antenna. The research GPS antenna was installed inside the aircraft under the glare shield.

Consideration was given for the composite construction of the aircraft and the lack of metal surface to provide a good antenna ground plane. Additional 0.020-in. thick aluminum sheet and conductive aluminum tape was used to cover surfaces inside the aircraft in order to provide a better antenna ground plane. This additional surface was electrically connected to the antenna adapters and to a central ground location in the aircraft. The central ground was connected to the aircraft engine mount using eight-gauge wire. Low-loss 50-ohm RG-400 coaxial cable was used to connect all antennas to their respective equipment. A research antenna installation is shown in Figure 8.

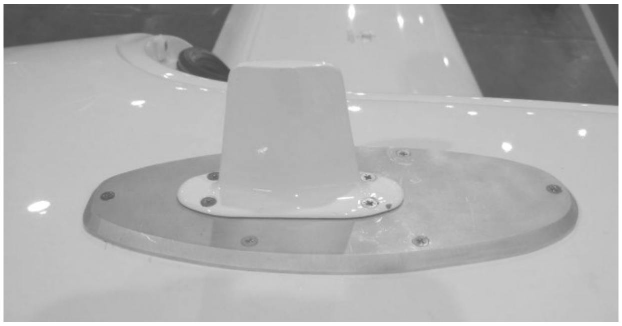

Figure 8. Research Antenna Installation

Integration Testing

Personnel from NASA Langley installed the research equipment and mounts on the research equipment pallet, followed by the associated power, control, and interface wiring. Integration testing began when these two activities were completed, but before the pallet was mounted in the aircraft. The initial integration tests for the fully-populated pallet were performed in a ground-based integration laboratory. Initial tests were performed for all pallet mounted equipment. All of the mechanical and electrical pallet components also were inspected and approved by NASA Langley quality-assurance personnel for safety-related defects. Those defects identified during the integration testing and inspections were corrected prior to the installation of the pallet in the aircraft.

After the laboratory integration testing was completed, the research equipment pallet was installed in the aircraft. Additional aircraft power and interface wiring was completed with the research equipment pallet mounted in the cargo compartment. In-situ tests were then performed for all of the research systems, using both external power and internal aircraft power. During these tests, the sensors were tested and calibrated, and data were recorded by the DAS. Pre-flight and operational procedures were developed for all of the research systems at this time. Additional wiring problems were identified and corrected through this process. The installed research equipment pallet is shown in Figure 9. Individually, all of the research systems were found to work satisfactorily. However, a major problem with electromagnetic interference (EMI) was discovered during the in-situ integration testing and is discussed below.

Figure 9. Research Equipment Pallet

Electromagnetic Interference Testing

During the in-situ integration testing, noise was often heard in the basic aircraft VHF radio and interphone system. This symptom was the first indication of an EMI problem. Further testing demonstrated that the problem was system and frequency dependent. NASA Langley EMI experts were solicited to quantify the problem and recommend solutions. A sophisticated frequency spectrum analyzer was used to characterize the overall EMI situation and identify specific EMI sources.

The major EMI sources were found to be the two general-purpose computers, the CAIS CDAU, and several cables carrying RS-232 and video signals. The VHF communications transmitters were also found to be inducing EMI into the research systems. The EMI problems were further complicated by the composite construction of the airframe (low inherent shielding properties), and the close proximity of the antennas, receivers, and transmitters to each other and to the research components. Finally, the implementation team discovered that the traditional techniques that had been used previously in larger, all-metal aircraft for grounding and shielding the research cables were not adequate for this aircraft

The EMI from the general-purpose computers was eliminated by placing a braided shield over the cables connected to these computers and by inserting in-line filters at the connectors for these lines. The EMI from the CDAU in the CAIS was eliminated by replacing the internal power supply in the CDAU with a re-designed, low-noise version provided by the vendor (TTC). The following generic techniques were used throughout the baseline GA research system: shielded all cables to and from the research system; terminated all shields to a chassis ground using a braided strap; terminated all shields to chassis ground at a point of break where possible (for example, an interface panel or terminal block); used EESeal commercial in-line EMI filters on all connectors in the research system.

Flight Testing

A total of three Instrument Check Flights (ICF's) were flown to verify the proper operation of the Phase I research system before research data flights could begin. The first ICF was also used to calibrate the ADAHRS and its associated magnetometer, verify that the research systems did not interfere with the basic ship's avionics, and characterize the UAT and VHF radio modem performance. The second ICF was used to perform tests associated with the ADAHRS air data inputs and for the motion pack. These tests included several aircraft maneuvers including sweeps of altitude, airspeed, heading, alpha, and beta. The third ICF was used to repeat some of the previous tests and to verify proper operation of the modified Avidyne MFD. No major problems were discovered during the ICF's and the aircraft was released to the SATS Project for use in its first in-house research experiment.

Phase II Plans

The final phase of baseline implementation in the Cirrus SR22X airplane will begin upon completion of the first flight-test series. Phase II implementation includes the following components: a data/video telemetry system; additional displays, including a primary flight display (PFD); the addition of a tail-mounted video camera; video recording switches and other remote controls; a two-way Airborne Internet data link; general-purpose computer upgrades; and a re-designed main instrument panel incorporating both the MFD and the PFD. The instrument panel will be modified to accommodate both a PFD and MFD on the left side for research purposes, and will utilize certified instruments on the right to maintain full instrument flight rule (IFR) capability. The stylized panel as manufactured, extends approximately 80 percent across the cockpit, and the right half is angled towards the left-seat occupant for better viewing. The panel will be extensively modified to extend completely across the cockpit, and vertically 2-inches to gain valuable panel space (see figures 10, 11).

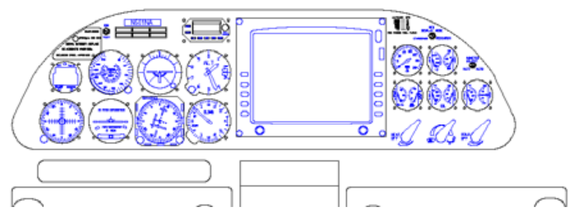

Figure 10. Phase I Instrument Panel

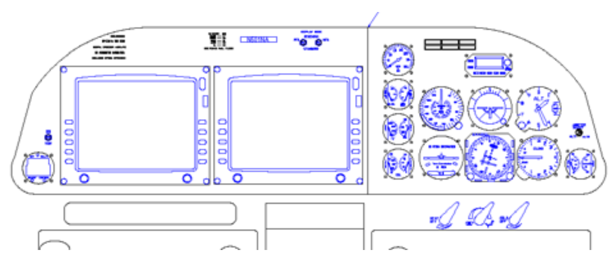

Figure 11. Phase II Instrument Panel

Phase I Modifications to the Lancair Columbia 300X and the Cessna 206X Aircraft

The lessons learned on the Cirrus SR22X aircraft are being applied to the research installations being made on the Lancair Columbia 300X and Cessna 206X GA research aircraft at NASA Langley. The research modifications to these two aircraft are being made in accordance with research requirements and the availability of funding.

The modifications to the Lancair Columbia 300X airplane have been limited to the installation of a research power system and an empty research equipment pallet, which has been installed in the cargo compartment of the aircraft. Both the research power system and the research equipment pallet are identical to those installed on the Cirrus SR22X aircraft.

The Cessna 206X aircraft has been equipped with the following baseline research components: research power source; ADAHRS; researcher workstation in the right rear seat; single flat-panel display mounted in the main instrument panel; sensor suite; Capstone avionics suite; and, two research pallets. Research power is provided from the ship's power bus dedicated to the propeller anti-icing system. Therefore, when the research system is in use, the propeller anti-icing system is not available. The passenger cabin and cargo area in the Cessna 206X aircraft are large enough to accommodate two pallets. One of these pallets, manufactured using sheet metal and rivets, is located in the left rear corner of the passenger cabin, replacing the middle and rear seats on the left side of the airplane. A second pallet, based on the honeycomb design incorporated on the other two GA aircraft, is installed in the cargo compartment aft of the passenger cabin. Due to the geometry of the cargo compartment in the Cessna 206X aircraft, the standard pallet design had to be modified. In the Cessna 206X aircraft, the bottom and top shelves of the research equipment pallet are both the same size as the top shelves of the pallets used in the other two GA aircraft.

Conclusion

The Phase I configuration of a "General Aviation Baseline Research System" has been designed, fabricated and successfully installed in the NASA Langley Cirrus Design SR22X aircraft. Phase I systems include: independent research power system; research equipment pallet; data acquisition and recording; data link; GPS and DGPS; aircraft state, engine, surface positions, and air-data sensors; one flat-panel MFD in the main instrument panel; operator work station in the right rear seat; video recording; and two general-purpose research computers, which can generate displays for the research MFD. The net aircraft weight gain for all Phase I modifications was 230 pounds.

The Cirrus SR22X aircraft in the Phase I configuration is currently conducting the first of several SATS flight-research experiments. The resulting system is meeting NASA Langley's flight-research needs, and advancing the use of the latest technology in general aviation. The Phase II implementation, which will include such features as data and video telemetry and a research PFD, will commence at the conclusion of the current flight tests. The planned modifications will enhance the research capabilities of the Cirrus SR22X aircraft. The lessons learned on the Cirrus SR22X aircraft are being applied to the research installations being made on the Lancair Columbia 300X and Cessna 206X GA research aircraft at NASA Langley.

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